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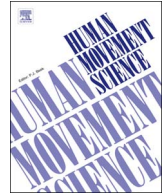
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Full Length Article

In situ examination of decision-making skills and gaze behaviour of basketball players

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ABSTRACT

In this study we examined in situ decision-making skills and gaze behaviour of skilled female basketball players. Players participated as ball carriers in a specific 3 vs 3 pick-and-roll basketball play. Playing both on the right and left side of the court and facing three types of defensive play, they chose and performed one of four options: shoot, drive to the basket, pass to the screener or pass to the corner player. We concurrently measured gaze behaviour to examine the direct relationship between gaze and decision making. As one of the first studies examining decision making and gaze behaviour in situ, this study found support for the embodied choice framework as the results showed that handling the ball with the dominant or non-dominant hand influenced the decisions that were made. Gaze measures suggested that peripheral vision may serve a significant role in decision making in situ, whereas players mainly relied on central vision to execute an action. Furthermore, this study underlined the need for developing and using newer and more informative methods to analyse gaze.

1. Introduction

Decision making is an important aspect of sport performance. In invasion games like basketball, soccer and hockey, a player has to read the game and decide upon and perform an appropriate action in a complex dynamic and time-constrained environment. It is well established that experts possess superior perceptual-cognitive skills including recognizing and recalling meaningful patterns of play (Gorman, Abernethy, & Farrow, 2012; Van Maarseveen, Oudejans, & Savelsbergh, 2015), predicting the outcome of another person's action on the basis of pick-up of early visual information (anticipation; Abernethy & Russell, 1987; Savelsbergh, Williams, Van der Kamp, & Ward, 2002; Williams & Ward, 2007), and making accurate decisions regarding the developing course of action (i.e., the ability to select the best possible option from a variety of alternatives; Gorman, Abernethy, & Farrow, 2013; Helsen & Pauwels, 1993; Roca, Ford, McRobert, & Williams, 2011; Vaeyens, Lenoir, Williams, Mazyn, & Philippaerts, 2007a; Williams & Davids, 1998; Williams, Davids, Burwitz, & Williams, 1994). An interesting question is how athletes make decisions in complex and time-constrained situations. This involves both the visual information relied upon and the cognitive processes needed to interpret the visual information and choose an option.

One possible way to gain insight into how athletes make decisions in complex and time-constrained situations is through the examination of gaze behaviour. Eye registration techniques have been increasingly used in sport science to gain insight into the visual

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search strategies of expert athletes and consequently to use these insights to improve the performance of lesser-skilled athletes, for example to enhance the visual control of the basketball shot (Oudejans, 2012; Oudejans, Koedijker, Bleijendaal, & Bakker, 2005) and the interceptive performance of soccer goalkeepers (Savelsbergh, Van Gastel, & Van Kampen, 2010). However, there is much unknown about the visual information relied upon for skilled decision making in complex dynamic situations. This may be due to some substantial limitations to using eye registration techniques to gain insight into gaze behaviour (Mann, Farrow, Shuttleworth, & Hopwood, 2009; Ryu, Abernethy, Mann, Poolton, & Gorman, 2013; Williams & Davids, 1998; Williams, Janelle, & Davids, 2004). First, when fixating at a certain location, this does not mean that the observer is able to pick up information from that fixation location; “looking” is not necessarily “seeing” (Williams et al., 2004). Second, eye tracking devices measure where an observer is foveally fixating, but this does not reveal where the observer’s attention is at that time. Many sport situations require integration of information from the fovea, parafovea, and visual periphery (Ryu et al., 2013; Williams & Davids, 1998; Williams et al., 2004). For example, Ryu et al. (2013) examined the role of central and peripheral vision in expert decision making using a gaze-contingent display selectively showing video footage to the central or peripheral area of the visual field. When central vision was removed, and thus peripheral vision could only be used, the skilled players did not change the amount of time they spent directing their central vision towards the ball-carrier in comparison with full vision, even though this meant that the ball-carrier could not be seen. This suggests that the participants used the location of the ball-carrier as an anchor point and monitored the movement of the other players using peripheral vision. Therefore, in normal conditions with full vision, the fixation location could reflect the observer’s attention via central vision or could be used as an anchor point to extract information from the visual periphery (visual pivot; Ryu et al., 2013; Williams & Davids, 1998). Third, visual search strategies appear to be very context specific. Watching the same situation for different purposes or tasks, results in different visual search strategies (Gorman, Abernethy, & Farrow, 2015; North, Williams, Hodges, Ward, & Ericsson, 2009; Van Maarseveen, Oudejans, Mann, & Savelsbergh, 2016). For example, Van Maarseveen et al. (2016) found differences in the gaze of soccer players when watching the same video clips for the purposes of anticipation, decision making and pattern recall. But also with identical purposes the visual search strategies differ when varying number of players are displayed in the video clip (Vaeyens et al., 2007a; Williams & Davids, 1998). Finally, it is difficult to capture the visual search strategies employed in dynamic sport situations with the traditionally used dependent variables like search rate and fixation duration (Mann et al., 2009), and thus there is a need to develop new methods to analyse gaze behaviour. Examples include time series graphs (Mann et al., 2009), eye fixation scan paths (Underwood, Phelps, Wright, Van Loon, & Galpin, 2005), and the combination of eye tracking and verbal protocols (Williams et al., 2004).

Moreover, decision-making skills and gaze behaviour have typically been measured using simplified video-based tests in which participants do not actually move, but respond verbally or by way of a button-press while concurrently wearing an eye tracking device. Although these simplified tests offer a significant advantage in terms of their methodological rigour and control, there is increasing evidence that these tests do not accurately represent the on-field performance they are designed to sample (Dicks, Button, & Davids, 2010; Mann, Abernethy, & Farrow, 2010; Mann, Williams, Ward, & Janelle, 2007; Pinder, Headrick, & Oudejans, 2015; Travassos et al., 2013; Van Maarseveen et al., 2016). First, significant differences have been found in both movement and visual behaviour when comparing performance on traditional video-based tests with contexts that are more representative of the actual performance environment (Dicks et al., 2010; Mann et al., 2010; Pinder et al., 2015). For example, Dicks et al. (2010) showed that soccer goalkeepers made more penalty saves and fixated earlier and longer on the ball when actual interception was required compared to when responding to a video simulation. Second, meta-analysis has shown that expertise effects are most apparent when participants have to perform real actions under in situ task constraints compared to simplified responses in less representative environments (Mann et al., 2007; Travassos et al., 2013). Third, Van Maarseveen et al. (2016) have shown that on-field performance of soccer players could not be predicted on the basis of performance on video-based tests of perceptual-cognitive skill.

The less representative research designs may be unsuitable to gain insight into expert performance in complex domains such as team sports due to decoupling of perception and action (Mann et al., 2010; Savelsbergh, Onrust, Rouwenhorst, & Van der Kamp, 2006). Decision making is not a serial process, in which the decision is made first and then the action is executed, but the perceptual and motor components of decision making seem to be intertwined. According to the framework of Embodied Choice “action performance is considered as a proper part of the decision making process” (Lepora & Pezzulo, 2015, p. 2) and not only the end product of the cognitive decision; instead there are bidirectional influences between actions and decisions. This implies that in sports, where decisions may be expressed as actions, the action dynamics and constraints (e.g., speed, body orientation, or handling the ball with the dominant or non-dominant hand or foot) influence the decision making process. Therefore, action and perception cannot be examined separately in such a complex domain as sports. This highlights the necessity of measuring perceptual-motor skills in the actual performance environment, thus using in situ research designs in which a natural perception-action coupling is preserved. Surprisingly though, hardly any studies have been conducted on the direct relationship between decision-making skills and gaze behaviour using an in situ design (for an exception see Martell & Vickers, 2004). The current study is one of the first studies examining decision making and gaze behaviour during actual play situations on the court (thus in situ), with the aim to directly relate gaze behaviour to decision-making performance. To this end, skilled basketball players performed 3 vs. 3 pick-and-roll plays on the court. The pick-and-roll is an offensive play in which a player sets a screen (“pick”) for his ball handling teammate and then moves (“rolls”) behind the defender towards the basket to get open for a pass. In this way, the team mate of the ball carrier blocks out the defender, creating space and time for the ball carrier. In this research design, the ball carrier had four options after the pick-and-roll: shooting at the basket, driving towards the basket followed by a lay-up, passing to the teammate who set the screen or passing to an additional teammate in the corner of the court. Playing both on the left and right side of the court and facing three different defensive plays, the ball carrier had to decide upon and perform one of the four options. We examined the differences in decisions among defensive plays and between sides of the court. We expected a different pattern of decisions for each of the defensive plays, and for

each side of the court as players handled the ball with their right hand on the left and with their left hand on the right side of the court (based on the framework of Embodied Choice, Lepora & Pezzulo, 2015).

During the pick-and-roll plays the ball carrier wore a mobile eye tracking device, so that we could explore the direct relationship between gaze behaviour and the decisions that were made. As this was the first time this was done, and given the fast amount of possibilities of examining gaze behaviour we chose to focus on the differences between correct and incorrect decisions. We examined where players looked during the dynamic development of each play to gain insight into the visual information that the players used to make their decisions and control their actions. Did they scan all four options and when and for how long did they look at the option that they chose (if at all)? Was gaze behaviour dependent on whether a correct or incorrect decision was chosen? Given the exploratory nature of this study we did not have a priori hypotheses concerning gaze behaviour.

2. Method

2.1. Participants

Thirteen skilled female basketball players participated in this study (six guards and seven forwards; M age = 16.9 years, SD = 1.3; M experience = 8.4 years, SD = 2.5; M length = 1.79 m, SD = 0.06 m). All played in the national basketball talent program, in which they trained about twenty hours a week, played competition in the highest Dutch league for women basketball, and all were selected for the Dutch national (youth) team. All players were right-handed. The experiment was approved by the ethics committee of the local research institute and all participants gave their written informed consent prior to the experiment; parental consent was provided for players younger than 18 years.

2.2. Equipment

The test took place at the regular training facilities of the national basketball talent program. Official FIBA regulation court, basket and women's basketball (size 6) were used. All trials were recorded with a GoPro camera (Hero 3, black edition, GoPro, Inc., USA) from 5 m above the ground (Fig. 1). The SensoMotoric Instruments Eye Tracking Glasses (SMI; Teltow, Germany; binocular, 24 Hz) were used to record the gaze behaviour of the participants. The glasses were connected to a mobile recording unit which was carried in a waist bag and enabled the participant to move freely. The Eye Tracking Glasses were calibrated using a 3-point calibration and the calibration was checked and adjusted if needed prior to each trial. All participants had worn the SMI Eye Tracking Glasses before, so they were familiar with wearing the glasses. The process of putting on the glasses, attaching the waist bag and calibrating the Eye Tracker took about 5–10 mins.

2.3. Procedure and design

The test consisted of 3 vs. 3 pick and roll plays, that is, two offensive players played a pick and roll and one additional offensive

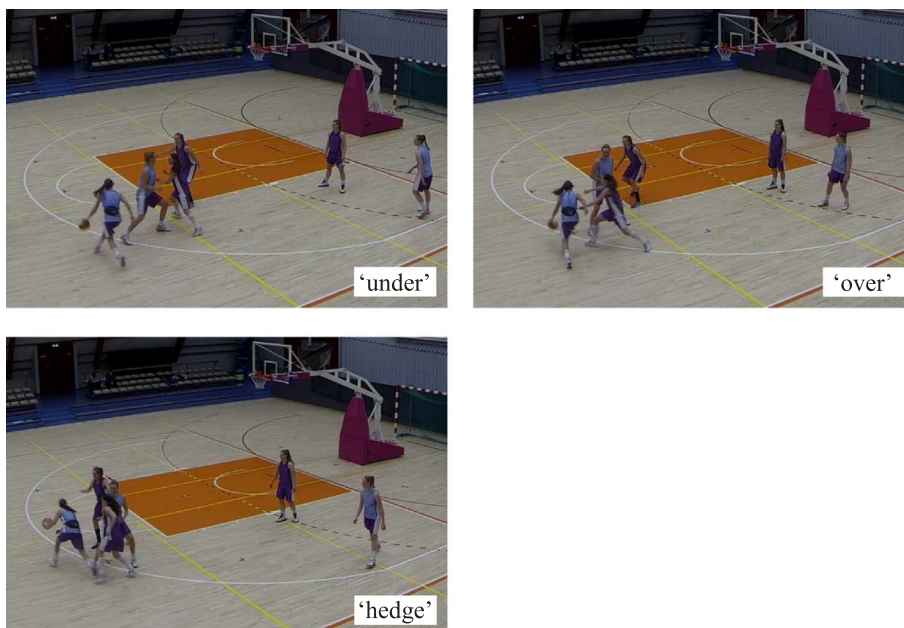


Fig. 1. Snapshots of the GoPro video footage, 3 vs. 3 pick and roll with defensive play 'under', 'over', and 'hedge'.

player was in the corner of the court. The offensive players were defended by three defensive players. Each participant participated 36 times in the pick and roll play as the ball handler, 18 times on the left side of the court and 18 times on the right side, counterbalanced across participants. Of those 36 trials, the participant wore the SMI Eye Tracker in the first 12 trials, that is, 6 trials on the left and 6 trials on the right. The 24 trials without eye tracking glasses were added to increase the amount of decision data and the power of the study. Besides the participant who played as ball handler, five players of the talent program acted as supporting cast (i.e., 2 offensive players and 3 defensive players). The participants performed the 36 trials in 3 series of 12 trials, roles were switched after each series. A series of 12 trials took about 5 mins. The participant performed the three series on separate days.

Every trial started with a signal of the experimenter. The participant moved towards the experimenter to receive the pass from the experimenter. Then the pick and roll play started. The screener set a screen, the ball handler dribbled off the screen and the screener moved ('rolled') towards the basket. The ball handler had four options: take a shot, drive towards the basket for a lay-up, pass to the screener/roller or pass to the corner player. Before every trial, the defenders were instructed by the experimenter about which defensive play they had to perform: 'under', 'over' or 'hedge'. In the defensive play 'under', the defender who defended the ball handler moved under the screen trying to defend the ball handler, in the defensive play 'over', the defender followed the ball handler and thus moved over the screen, and in the defensive play 'hedge', the defender of the ball handler and the defender of the screener both stepped out towards the ball handler to put her under pressure, see Fig. 1.

2.4. Data analyses

2.4.1. Decision data

For each trial, the decision of the ball handler and the quality of the decision were registered. The possible decisions were shoot, drive, pass to the screener/roller and pass to the corner player, and in some cases no decision was made as the ball handler lost ball possession before making and executing the decision. We compared the trials in which the players did or did not wear eye tracking glasses to determine whether wearing the eye tracking glasses influenced the decisions that were made by the players. Execution time was defined as the duration from catching the ball after receiving the initial pass until releasing the ball for pass, lay-up or shot. To analyse the quality of the decisions, two coaches of the talent program carefully observed the video footage and indicated, for each trial, whether the player made a correct or incorrect decision, and if an incorrect decision was made, what the correct decision would have been. Interobserver reliability was assessed on a subset of 78 trials (i.e., 17%), and was found to be substantial, Kappa = 0.66, $p < .001$.

2.4.2. Gaze behaviour data

The recordings of the SMI Eye Tracking Glasses were synchronized with the video footage of the GoPro camera using Cyberlink PowerDirector 11 (CyberLink™ Corp). These synchronized video files were analysed frame-by-frame for the duration of each trial. A trial started when the player caught the ball thrown by the experimenter and ended when the player released the ball (for pass, lay-up or shot). A fixation was defined as gaze maintained on any location for a period equal to or in excess of 125 ms or three sequential frames (cf. Savelsbergh et al., 2002; Vaeyens et al., 2007a; Vaeyens, Lenoir, Williams, & Philippaerts, 2007b; Williams & Davids, 1998). For each player, the first three trials were coded by two experimenters to assess interobserver reliability and it was found that Kappa = 0.95, $p < .001$, an almost perfect agreement.

To gain insight into the visual search strategies employed by the players we subjected the gaze behaviour data to several analyses. *First*, we examined when the players fixated on the option that they chose by creating time series graphs that demonstrated the fixations on the chosen option across the progression of the trial, similar to Mann et al. (2009). To produce the time series graphs each trial was broken down into intervals representing 5% of the total length of the trial (since trial duration was not equal across trials), and we calculated the percentage of trials in which the player directed her gaze at the chosen option for each 5% increment. We then calculated how often the final fixation (i.e., the last fixation in the progression of the trial) was on the option that the player chose and how long this fixation was. *Second*, we were interested in what visual information the players relied on before they fixated on the option that they eventually chose. Therefore, we examined where the players were looking at prior to the final fixation on the chosen option by calculating the percentage of time the players spent fixating each of nine fixation locations: ball handler defender (BHD), screener/roller (SR), screen defender (SD), corner player (CP), corner defender (CD), ball (Ball), basket (Bask), free space in between players (FSI) and free space outside players (FSO). *Third*, we were interested in the scan paths the players displayed and therefore identified two-fixation scan paths for each of the chosen options, similar to Underwood et al. (2005). To do so, Markov matrices were produced, displaying the probabilities of a transition from any one fixation location to any other. Refixations within the same locations were excluded from analysis, as we were only interested in transitions from one location to another. *Finally*, we calculated how often the players had fixated on the correct option when they made an incorrect decision. In all gaze analyses, we were especially interested in the differences between the correct and incorrect decisions.

2.4.3. Statistical analyses

The mean quality of the decisions in the trials with and without eye tracking glasses were analysed using a paired samples *t*-test. Subsequently, the quality of the decisions was analysed with a 3 (defensive play) \times 2 (side) ANOVA with repeated measures on both factors. The frequencies of decisions were analysed using loglinear analyses, and if necessary followed up by likelihood ratio chi-square tests on the different levels of one of the variables. Execution time of the correct and incorrect decisions was analysed using a paired samples *t*-test. Separate likelihood ratio chi-square tests were used to analyse the number of trials in which the final fixation was on the chosen option, and the number of trials in which the players fixated on the correct option when making an incorrect

decision. The percentage viewing time was first analysed using a 4 (option) \times 9 (fixation location) ANOVA with repeated measures on the last factor to examine the differences between the four options that could be chosen, and subsequently with a 2 (quality decision) \times 9 (fixation location) ANOVA with repeated measures on both factors to examine the influence of the quality of the decisions. Additionally, Pearson correlations were calculated between the percentage of viewing time towards the nine fixation locations and the percentage of trials in which the player choose the correct option. The fixation transition probabilities were evaluated using binomial tests to identify the fixation transitions that occurred more frequently than expected by chance. Given that there were nine fixation locations, the expected probability of a transition from one location to any other was $1/8 = 0.125$. Significant chi-square tests were broken down with standardized residuals and significant ANOVAs were followed up by Bonferroni corrected pairwise comparisons. The significance level was set at .05, effect sizes were reported as odds ratios for chi-square tests and partial eta squared (η_p^2) for ANOVAs.

3. Results

3.1. Influence wearing eye tracking glasses

When comparing the trials in which the players did and did not wear eye tracking glasses, no interaction effects were found for wearing the glasses on the decisions that were made, $\chi^2_s < 6.232$, $ps > .182$. The lack of interaction reflects similar decisions across sides and defensive plays while wearing and not wearing eye tracking glasses. Furthermore, a paired samples *t*-test did not reveal a significant difference between the mean quality of the decisions in the trials with and without eye tracking glasses, $t(13) = 1.108$, $p = .290$, $r = .29$. Therefore, the data were collapsed across both conditions for the remainder of this study.

3.2. Decisions

Fig. 2 shows the accuracy of the decisions for the three defensive plays and the left and right side of the court. There was no difference in the accuracy of the decisions between the defensive plays, $F(1, 24) = 1.396$, $p = .267$, $\eta_p^2 = .104$, nor between the left and right side of the court, $F(1, 12) = .006$, $p = .938$, $\eta_p^2 = .001$, and there was no significant interaction effect, $F(2, 24) = 2.073$, $p = .148$, $\eta_p^2 = .147$, implying that these factors (defensive play and side of the court) did not significantly influence the quality of the decisions, that is, how many correct and incorrect decisions were made. However, these factors did lead to different patterns of decisions as can be seen in Fig. 3, which shows the distribution of the decisions per defensive play for the left and right side of the court.

The three-way loglinear analysis on the number of decisions in the different categories revealed that the highest order interaction (side \times defensive play \times decision interaction) was significant, $\chi^2(8) = 16.865$, $p < .05$. To interpret this interaction chi-square tests on the defensive play and decisions were performed separately for the left and right side. There were significant associations between the defensive play and the decisions that were made on both sides of the court, but the association was stronger on the left, $\chi^2(8) = 91.878$, $p < .001$, than on the right side of the court, $\chi^2(8) = 56.955$, $p < .001$, indicating that the players were more likely to base their decision on the defensive play that they faced on the left than on the right. Odds ratios indicated that on the left, the players had a clear preference for shooting when facing defensive play ‘under’ (odds ratio 13.8, i.e., the odds of shooting were 13.8 times higher when facing ‘under’ than when facing another defensive play), and a preference for passing to the screener/roller or corner player when facing a ‘hedge’ (odds ratio 2.4 and 3.2, respectively). On the right, the preference for shooting when facing ‘under’ was weaker (odds ratio 5.3) than on the left. When facing a ‘hedge’ on the right, the players showed a preference for passing to the corner player (odds ratio 2.7), and the odds of making ‘no decision’ were 5.0 times higher when facing a ‘hedge’ in comparison to facing other defensive plays. Thus, the analysis revealed that the playing side, and thus the hand with which the players handled the ball, influenced the decisions that the players made.

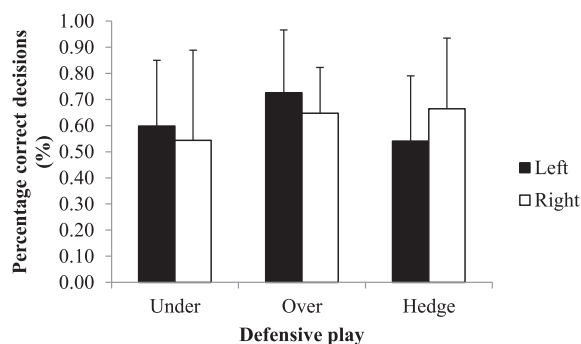


Fig. 2. Accuracy of the decisions for the three defensive plays and the left and right side of the court.

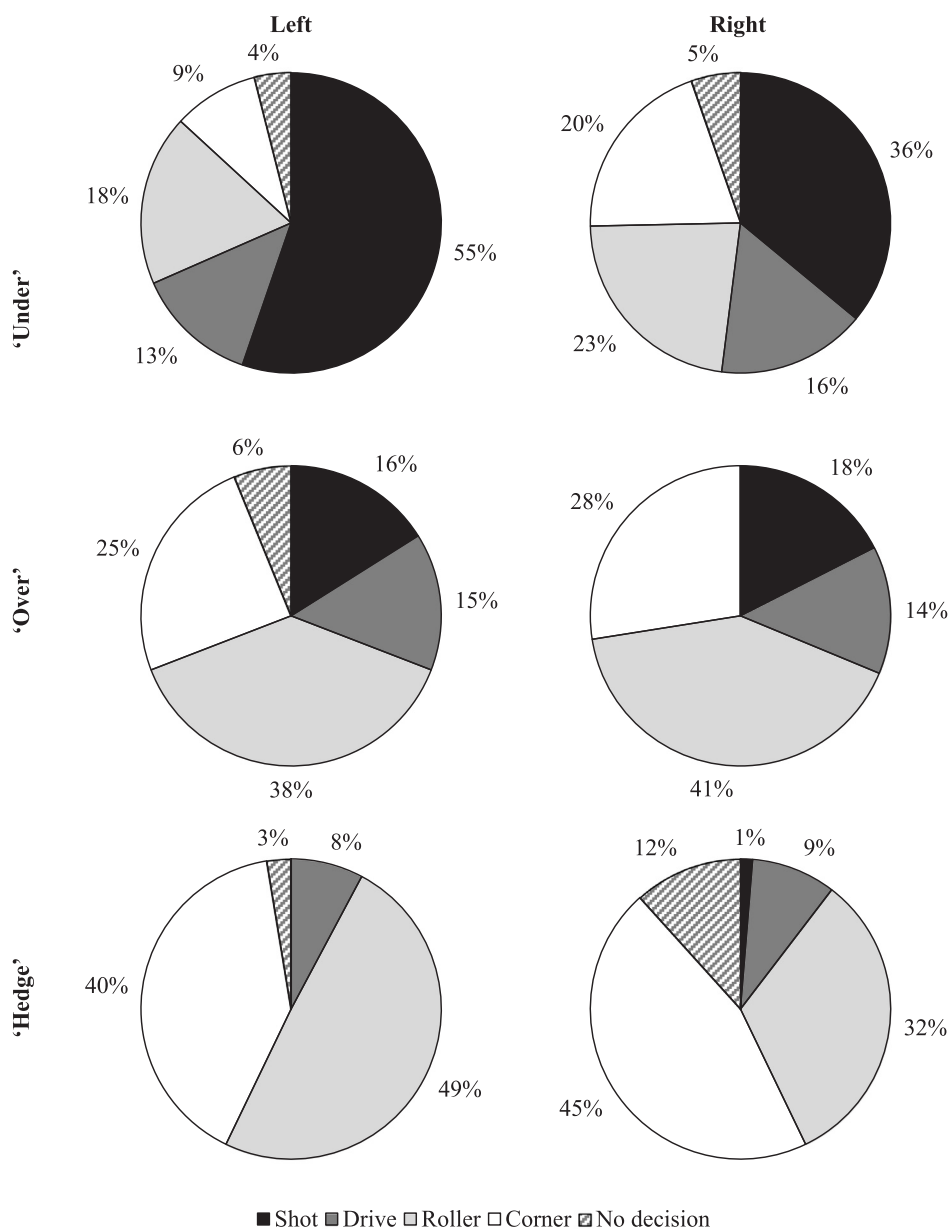


Fig. 3. Distribution of decisions per defensive play and side of the court.

3.3. Execution time

Trials in which a correct decision was made had an average execution time of 2652 ms ($SD = 348$ ms) and trials in which an incorrect decision was made had an average execution time of 2951 ms ($SD = 665$ ms). The paired samples t -test approached significance indicating that execution time of correct trials seems to be shorter than those of incorrect trials, $t(11) = 1.847$, $p = .092$, $r = .49$.

3.4. Gaze behaviour

3.4.1. When and for how long did the players fixate on the option they chose?

Fig. 4 shows time series for the percentage of trials in which the players fixated on the option they chose, for each of the four options. Although the players did not always fixate on the option they chose, it is clear that in general the players fixated on the option they chose at the end of the trial. When players decided to shoot or drive, they fixated earlier in the progression of the trial on the basket, in comparison with fixating their teammate when they decided to pass to the screener/roller or corner. The option roller

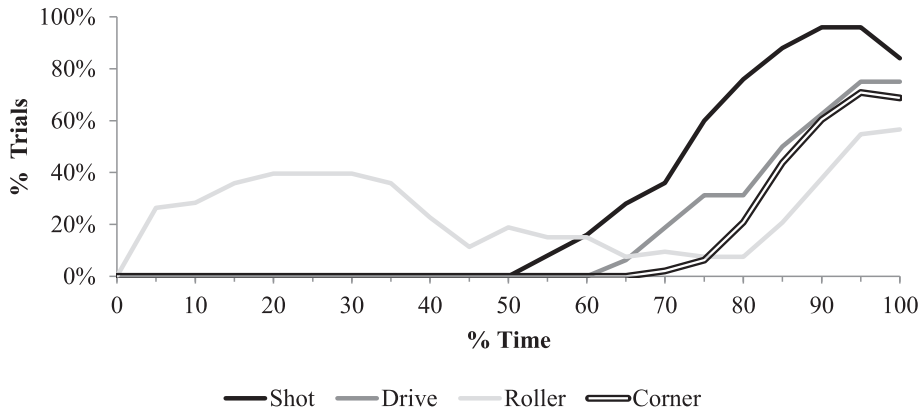


Fig. 4. Time series for the percentage of trials in which players fixated on the option they chose.

was also fixated in an earlier stage of the trial. Excluding the trials in which the player did not fixate on the chosen option at all, in 95 out of 118 trials (80.5%) the *final* fixation was on the option that they chose. When the players decided to drive, their final fixation was always on the basket (12 out of 12 trials, 100%), and when the players decided to shoot or pass to the corner their final fixation was often on the option they chose (shoot: 21 out of 25 trials, 84%; corner: 33 out of 35 trials, 94.3%), whereas when players decided to pass to the roller, their final fixation was only in 29 out of 46 trials (63%) on the roller, $\chi^2(3) = 16.274, p < .001$. There was no difference in the number of final fixations on the chosen option between the correct (59 out of 72 trials, 81.9%) and incorrect decisions (36 out of 46 trials, 78.3%), $\chi^2(1) = .240, p = .624$. The duration of the final fixation on the chosen option was on average 677 ms ($SD = 166$ ms) for shots, 611 ms ($SD = 300$ ms) for drives, 342 ms ($SD = 199$ s) for passes to the screener/roller, and 429 ms ($SD = 206$ ms) for passes to the corner player.

3.4.2. Where were the players looking at before they fixated on the option they chose?

Fig. 5 shows the percentage of viewing time that the players spent fixating on the nine fixation locations before they fixated on the option they chose. The analysis of the percentage viewing time for the different options revealed a main effect for fixation location, $F(3.04, 419.37) = 77.135, p < .001, \eta_p^2 = .359$. The players spent most time fixating on the screener/roller, screen defender, free space in between players, and free space outside players. There was no significant option \times fixation location interaction, $F(9.12, 419.37) = 1.661, p = .095, \eta_p^2 = .035$, indicating that the percentage of time players spent fixating the nine fixation locations was not influenced by the option that the players chose. Analysis of percentage viewing time collapsed across the four options revealed no significant quality decision \times fixation location interaction, $F(8, 88) = .478, p = .868, \eta_p^2 = .042$.

Pearson correlations between the percentage of viewing time towards the nine fixation locations and the percentage of trials in which the player choose the correct option are displayed in Table 1. Only the viewing time towards the free space outside players was significantly negatively related to the performance of the players, and a near significant positive relationship was found for the viewing time towards the free space in between players. These correlations indicated that the higher the percentage of correct decisions the lower the percentage viewing time towards the free space outside players and a trend for a higher percentage viewing

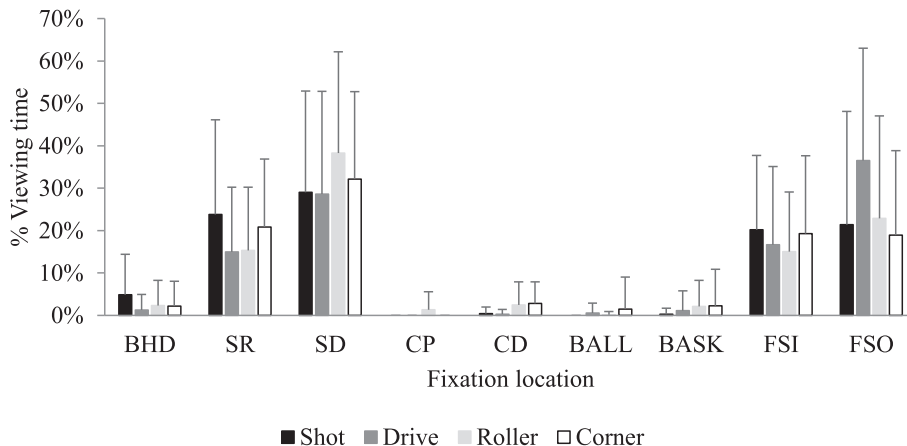


Fig. 5. Percentage viewing time to the nine fixation locations before fixating on the option that was chosen. Fixation locations: ball handler defender (BHD), screener/roller (SR), screen defender (SD), corner player (CP), corner defender (CD), ball (Ball), basket (Bask), free space in between players (FSI) and free space outside players (FSO).

Table 1

Pearson correlation between the percentage viewing time towards the nine fixation locations and the percentage of trials in which the player chose the correct option.

	<i>r</i>	<i>p</i>
BHD	.08	.806
SR	.14	.645
SD	.37	.216
CP	−.05	.872
CD	−.23	.454
Ball	−.12	.694
Bask	.07	.824
FSI	.51	.077
FSO	−.71	.007

Note. Fixation locations: ball handler defender (BHD), screener/roller (SR), screen defender (SD), corner player (CP), corner defender (CD), ball (Ball), basket (Bask), free space in between players (FSI) and free space outside players (FSO).

time towards the free space in between players.

3.4.3. Which scan paths did the players display for each of the chosen options?

Fig. 6 shows the two-fixation scan paths that were statistically over-represented among all possible transitions ($p < .05$) for each of the chosen options and for correct and incorrect decisions. The circles represent the nine fixation locations; the size of the circle represents the total percentage viewing time towards the location, also numerically displayed in the percentages under the name of the fixation location. The arrows represent the fixation transitions; the thickness of the arrow represents the probability of the fixation transition, also numerically displayed beside the arrow. For example, the probability of fixating on the basket after having fixated on the screen defender was 0.344 when players decided to shoot.

The scan paths show differences in visual search between each of the chosen options. When players decided to pass to the screener/roller or corner, they revealed more different over-represented fixation transitions than when they decided to shoot or drive, implying that the visual search strategies when passing are more diverse than for individual actions (i.e., shot or drive). Also, the scan paths revealed different visual search strategies between correct and incorrect decisions; the incorrect decisions were accompanied with an over-representation of fixation transitions from more remote fixation locations (i.e., basket and corner defender) towards the screener/roller (SR) or the space in between the players (FSI), while for the correct decisions the majority of over-represented fixation transitions were between the screener/roller, screen defender and the space in between the players.

3.4.4. Did the players look at the correct option when they made an incorrect decision?

If an incorrect decision was made, then in only 12 out of 56 trials (21.4%) the player had directed her gaze towards the correct option. This implies that when players made an incorrect decision, on most occasions they had not fixated the correct option.

4. Discussion

The aim of the current study was to examine the direct relationship between gaze behaviour and decision making of skilled basketball players as they performed pick-and-roll plays on the court. The pick-and-roll is an offensive play, which is frequently used in basketball. Playing both on the left and right side of the court and facing three different types of defence, the ball carrier had to decide upon and perform one of four options (shoot, drive, pass to screener/roller, or pass to the corner player), while concurrently wearing a mobile eye tracking device. The findings comparing the trials with and without eye tracking glasses revealed that wearing the glasses did not influence the decisions of the players nor the quality of the decisions. As such, this study shows that using eye tracking in situ does not (necessarily) interfere with task execution and performance, implying that eye tracking provides a powerful tool to investigate the relationship between perception, decision-making and action in situ, also in complex sports contexts. The availability of such a tool is in line with earlier suggestions that in situ research designs should be used to accurately capture perceptual-motor performance of athletes (Dicks et al., 2010; Mann & Savelsbergh, 2015; Mann et al., 2007, 2010; Pinder et al., 2015; Travassos et al., 2013; Van Maarseveen et al., 2016; Williams & Ericsson, 2005), and opens up many opportunities for future research.

The results of this study showed that the players made different decisions when they faced different defensive plays, but the quality of these decisions did not differ between the defensive plays. As there was also variation in the correct options indicated by the coaches per defensive play and differences in the scan paths per chosen option, this collectively indicates that the players were actually reading the game and not solely relying on team rules. The results also showed that the players made different decisions when they played with their dominant or non-dominant hand. To protect the ball from getting stolen by a defender, basketball players dribble with their hand farthest away from the defender and use their body to shield the ball. As all players in this study were right-handed, this meant that they handled the ball with their dominant hand when playing on the left side of the court, and handled the ball with their non-dominant hand on the right. Based on the embodied choice framework (Lepora & Pezzulo, 2015), handling the

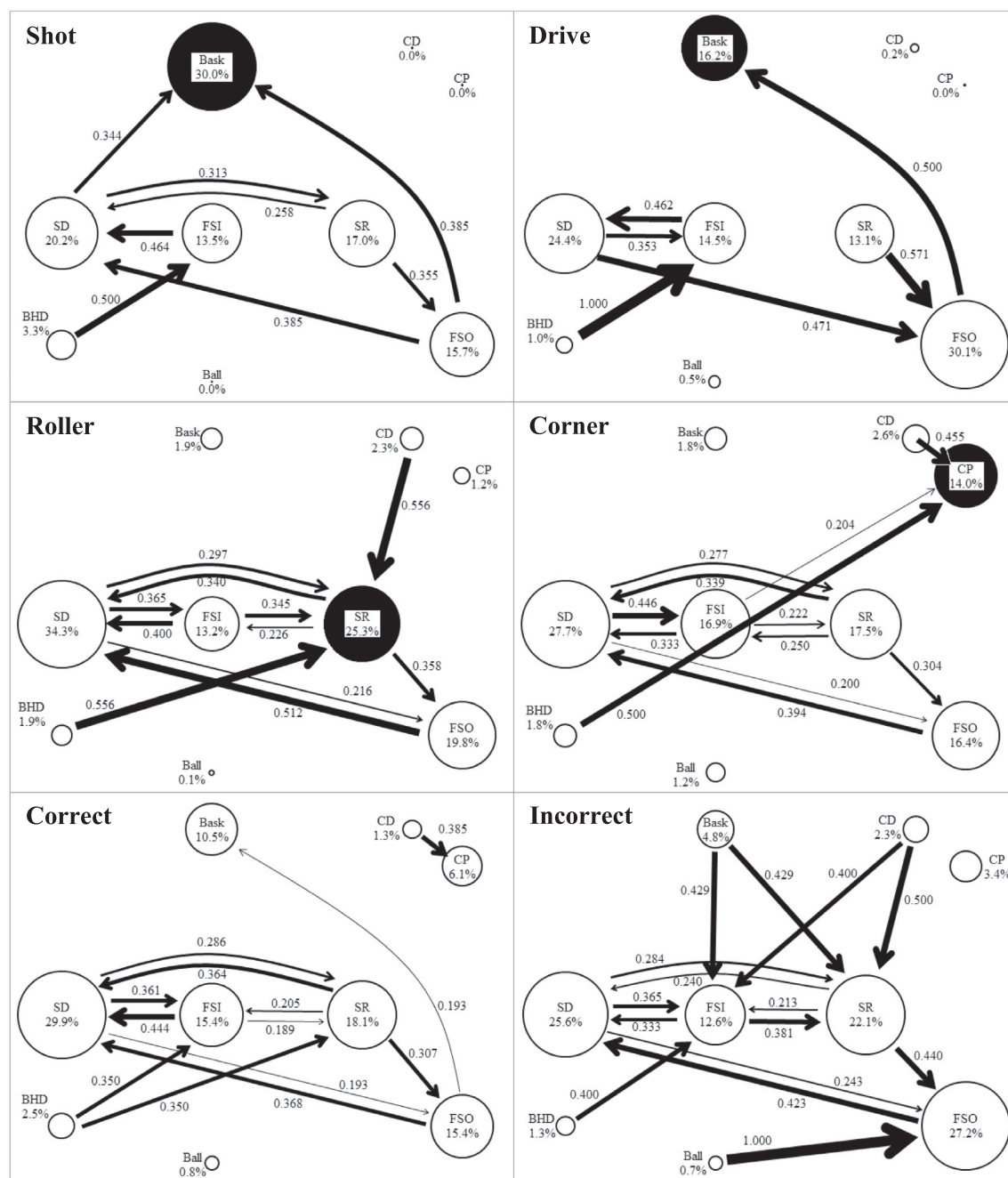


Fig. 6. Scan paths that were statistically over-represented among all possible transitions, for each of the chosen options and for correct and incorrect decisions. The circles represent the nine fixation locations: ball handler defender (BHD), screener/roller (SR), screen defender (SD), corner player (CP), corner defender (CD), ball (Ball), basket (Bask), free space in between players (FSI) and free space outside players (FSO). The size of the circle represents the total percentage viewing time towards the location, also numerically displayed in the percentages under the name of the fixation locations. The arrows represent the fixation transitions. The thickness of the arrow represents the probability of the fixation transition, also numerically displayed beside the arrow.

ball with the dominant hand results in different constraints and more or other action possibilities than handling the ball with the non-dominant hand, and therefore different decisions and possibly more accurate decisions could be expected. The current study did not show better performance (i.e., higher decision accuracy) when handling the ball with the dominant compared to the non-dominant hand. However, the players did make different decisions when handling the ball with the dominant or non-dominant hand. When the players dribbled with their dominant hand and faced the defensive play 'under' they more often chose to shoot, whereas they more often passed when dribbling with the non-dominant hand. When the players faced a 'hedge', they chose more often to pass to the screener/roller on the left (dominant hand) and to pass to the corner on the right (non-dominant hand). Facing a 'hedge' on the right

also more often resulted in ‘no decision’ than on the left. Passing to the screener/roller is a riskier option, but if performed correctly the player who receives the ball has an open line to the basket, whereas passing to the corner player seems to be a safer option. Thus, when handling the ball with the dominant hand, dribbling to become free and taking a shot or passing to an advantageous but risky option may be easier than when handling the ball with the non-dominant hand. So, this study showed, using an in situ research design, that the action (i.e., dribbling with the dominant or non-dominant hand) influenced the decisions that were made, thus supporting the embodied choice framework (Lepora & Pezzulo, 2015).

The gaze behaviour measures offered useful insights into the visual search strategies of the players when performing on the court. As vision is important to control perceptual-motor actions (e.g., De Oliveira, Huys, Oudejans, Van de Langenberg, & Beek, 2007; Oudejans, Karamat, & Stolk, 2012; Vickers, 1996), one could expect that the players would fixate on the option they chose just before ball release, meaning that the players fixate on the basket when shooting or driving, and on the corresponding teammate when passing. Our findings reveal that in 83.1% of the cases the players did indeed fixate on the option they chose. The time series graphs show that the players mainly looked at the option they chose at the end of the trial. In support, when excluding the trials in which the player did not fixate on the chosen option at all, in 80.5% of the remaining trials the final fixation was on the chosen option. Collectively, these findings show that to execute a perceptual-motor action, the players mainly relied on central vision. In particular, shooting seems to rely heavily on central vision; if the players chose to shoot, they always fixated on the basket. The duration of this final fixation on the basket was on average 677 ms, which is comparable to earlier studies (Oudejans et al., 2012), and which has been shown to be sufficiently long for accurate shooting; approximately 350 ms is necessary and sufficient for accurate control (Oudejans, Van de Langenberg, & Hutter, 2002).

In contrast to the high reliance on central vision for controlling an action, for decision making in a complex and dynamic situation peripheral vision is of eminent importance (Ryu, Abernethy, Mann, & Poolton, 2015; Ryu et al., 2013). Although we did not manipulate central and peripheral vision, the current study found some indications of the important role of peripheral vision when making decisions in situ, by examining scan paths and the locations the players directed their gaze to before fixating on the option they chose. The findings revealed that the players spent most time fixating on the screener/roller, the screen defender, and the free space in between the players before fixating on the chosen option. Given that these fixation locations are located close to each other, the high percentage of viewing time towards these areas (69.7% collectively) suggests that the players may have used a point in this area as an anchor point for foveal gaze and detected information about the developing situation using both central and peripheral vision. This is in accordance with the findings of Ryu et al. (2013, 2015), who investigated the role of central and peripheral vision in a video-simulated decision-making task using a gaze-contingent paradigm. In their study, skilled and less-skilled basketball players watched video clips of basketball scenarios with full vision, central vision only or peripheral vision only, and at the conclusion of each clip had to indicate whether it was better for the ball-carrier to pass to a teammate or drive to the basket. The findings revealed that the skilled players were superior regardless of whether they had full vision or either central or peripheral vision alone, indicating that skilled athletes can use both their central and peripheral vision to underpin decision making (Ryu et al., 2013). Furthermore, their findings revealed that the skilled players used the ball-carrier as an anchor point, and monitored the relative movement of the other players using peripheral vision (Ryu et al., 2013). Similarly, the players in our in situ study mainly directed their gaze to the most important area in this task design, that is the area capturing the screener/roller and screen defender, and could have used this area as their ‘visual pivot’ to extract visual information from the periphery (cf. Ripoll, 1988; Ripoll, Kerlirzin, Stein, & Reine, 1995). This was also supported by the correlation analysis and the scan paths. Correlation analysis revealed that the better the performance of the player (i.e., a higher percentage of correct decisions), the higher the percentage viewing time towards the space in between the players and the lower the percentage of viewing time towards the space outside the players. The scan paths showed differences between correct and incorrect decisions. The incorrect decisions were accompanied with an over-representation of fixation transitions from more remote fixation locations (i.e., basket and corner defender) towards the screener/roller or the space in between the players, while for the correct decisions the majority of over-represented fixation transitions were between the screener/roller, screen defender and the space in between the players, thus the more central fixation locations. This suggests that not only in video-based tests but also in situ peripheral vision seems to play an important role in decision making. Future studies using visual manipulations could further examine the role of central and peripheral vision in decision making in situ. Although the most obvious information is visual, athletes could also use auditory or tactile information to control complex motor actions (Gray, 2008). As we only examined visual information in this study, it would also be interesting for future studies to examine how athletes use and integrate multisensory information to inform their decision making.

The gaze analysis in this study both included traditionally used dependent variables (percentage viewing time) and newer analysis methods: time series graphs and scan paths. Using the more traditional gaze analysis method, we found that the percentage of time spend viewing the different fixation locations did not differ across the options that were chosen, which could be interpreted as a sign that (i) players use similar visual search strategies when they (eventually) decide to shoot, drive, pass to the screener/roller or pass to the corner player, or (ii) percentage viewing time is not an effective variable to capture visual search. In support of the latter, when using more advanced gaze analysis methods, the visual search strategies did seem to differ across the chosen options. The scan paths revealed differences in over-represented fixation transitions between each of the chosen options. There were more over-represented fixation transitions when players decided to pass than when they decided to shoot or drive, implying that the visual search strategies when passing are more diverse than for individual actions. Furthermore, the time series analysis showed that the players started looking at the chosen option earlier in the progression of the trial when they decided to shoot or drive than when they decided to pass. These insights could not be found using solely the traditional gaze measures like search rate, fixation duration and percentage viewing time. Therefore this study underlines the need for developing and using newer and more informative methods to analyse gaze.

In conclusion, as one of the first studies examining decision making and gaze behaviour in situ, this study found support for the embodied choice framework as the results showed that handling the ball with the dominant or non-dominant hand influenced the decisions that were made. Gaze measures suggested that peripheral vision may serve a significant role in decision making in situ, whereas players mainly relied on central vision to execute an action. Collectively, these results confirm the earlier suggestions that in situ research designs should be used to accurately capture perceptual-motor performance of athletes (Dicks et al., 2010; Mann & Savelsbergh, 2015; Mann et al., 2007, 2010; Pinder et al., 2015; Travassos et al., 2013; Van Maarseveen et al., 2016; Williams & Ericsson, 2005), and more advanced gaze analysis methods should be used to enhance our understanding of visual search (Mann et al., 2009). This study showed that decision-making skill and gaze behaviour can be measured successfully in situ, since the results revealed that wearing the eye tracking glasses did not influence the decisions of the players nor the quality of their decisions. As such, the results also point to the suitability of using in situ tests to measure performance of players for talent identification or evaluation of the effectiveness of interventions.

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